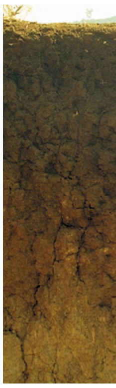
1. Understanding your soil



Soil formation

The soil, and the vegetation it supports, make up the life-supporting transition zone that lies between the underlying rocks and sediments of the earth and the atmosphere. Within the soil, there is a complex interaction of natural processes. These sustain an environment in which plants germinate and develop roots which have access to water and nutrients held in the soil. Soil forms and evolves on a time-scale of thousands of years.

The combined influences of the weather, the vegetation and animals, and chemical, physical, and biological processes generate soil.

A soil profile builds up on a foundation of parent material comprising raw rocks of enormous diversity, ancient weathered landscapes, or sediments deposited by wind and water. The upper slopes lose soil to the lower slopes through erosion by water, while more soil is added to the flats along creeks and rivers by flooding. In arid environments, wind moves soil around the landscape.

The least obvious influence on soil formation is the passage of time. Soils that range in age from a few years (on recent alluvium) to a few thousand years, all the way up to many millions of years are found in the farmlands of Australia.

The role of parent material

The physical and chemical properties of the parent material strongly influence the type of soil that is formed. This applies especially to the mix of sand, silt and clay—and the concentration of key nutrients such as phosphorus (P), potassium (K) and calcium (Ca).

Parent material that is rich in quartz (granite, coarse alluvium, ancient deeply-weathered landscape) gives rise to sandy or loamy soil low in P, while most basalt and many other fine-grained sediments (alluvium, silt-stone, shale) form soil of medium to high clay content associated with a medium to high level of P.

Clay that is young on a geological time-scale is usually of the cracking, or shrinking-swelling type (called smectite), which is made up of two parts silica to one part alumina. Clay that is more weathered becomes transformed; two forms of this type of clay are called koalinite and illite.

Soil loss exceeds soil formation

Although soil may be lost from the land surface through erosion by wind or water, new soil develops as the weathering processes extend below the present soil depth, converting parent rock into soil. The influence of water and transported soil chemicals, and of exploring plant roots, soil microbes and fungi, converts parent material at the lower extreme of a soil profile into living soil. The rate of soil formation at the interface with parent rock is only a few millimetres per century, and is much too slow to compensate for the accelerated rate of soil loss from the surface due to farming. This loss lowers potential productivity; for example, an average annual soil loss of only 2 t/ha, taken uniformly over a paddock, will result in a loss in soil depth of 20 mm after 100 years.

Soil physical properties

Structure and texture

The soil medium or matrix consists of a mix of air, water, and fine to coarse particles of weathered minerals, especially silica and silicates of aluminium. Particle sizes range from below 2 microns (0.002 mm) to above 2 mm. The fraction above 2 mm is classed as gravel and is considered to be of little significance in the agricultural soils of the northern grain belt.

The relative proportion of the three particle size categories, sand, silt and clay, determines the texture of the soil. This term refers to the behaviour of the soil when wet. Different textures are distinguished, based on feel (rough or smooth particles), cohesiveness—the length of a ribbon of wet (but not sticky) soil formed by squeezing out between the fore-finger and thumb—and capacity to retain water (see Module 5 – *Determining soil texture*).

The structure of the soil refers to the degree of development in the soil profile of aggregations of peds (the basic small units of structure, often just a few cubic mm in volume), and the strength of surface aggregates (crumb-like clusters of peds and organic particles). The opposite condition to aggregation is dispersion which causes a compacted layer to form, resulting in slowed movement of soil water. Well developed aggregates in turn are assembled into large ‘building blocks’ which generally are easily broken down in the hand or by cultivation into progressively smaller component units. Water and growing roots generally move freely in between the aggregates of a well-structured soil.

Structure also refers to the degree of development of layers in the profile, recognisable due to change in colour and/or texture.

Soil water

The amount of water that a crop can take up from a fully wet soil is referred to as the plant available water capacity (PAWC). When a clay soil is very wet but not saturated, practically all of the air space (pores) is filled with water. In a sandy soil (illustrated in Figure 1.1 on page 6), a much lower proportion of the pore space remains filled with water because water drains out of the large pore spaces between the particles (see Module 4).

Clay particles are extremely fine and packed closely together; a high proportion of the water held by a clay soil, within its peds, clings tightly to these particles. There is little drainage, but there is also limited uptake by the root. Usually less than half of the total water that is held in soil with high clay content can actually be taken up by roots.

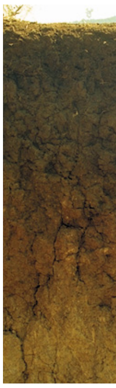
Apart from particle size affecting the physical behaviour of water, and causing different degrees of drainage, crop types differ in their ability to take up water from the soil. This is due to differences in depth and density of roots, differences in the duration of the growing season and differences in the ‘sucking power’ of the crop when it experiences water deficit (See Figure 1.2. and Module 4).

Soil water analysis

The next section helps to explain the results of soil water measurement through a brief presentation of some basic soil science.

The analysis sheet shown on the next page is output from the APSoil computer program. APSoil has been developed to link field information with appropriate soil characterisation data and to output information on water and nitrogen in a form appropriate to farmers.

Methods for obtaining the soil data required as input for APSoil are described in Module 2; methods of calculating Plant Available Water Capacity are described in Module 4.

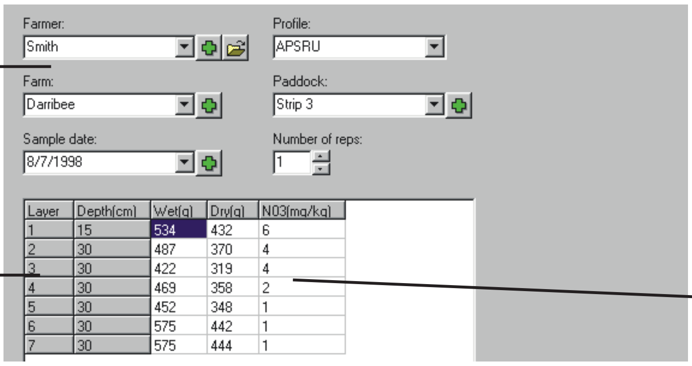


Soil water measurement

– an example of paddock reports from APSoil

Details of farmer, paddock and sampling visit.

Series of depth intervals or layers that were sampled (Module 2).

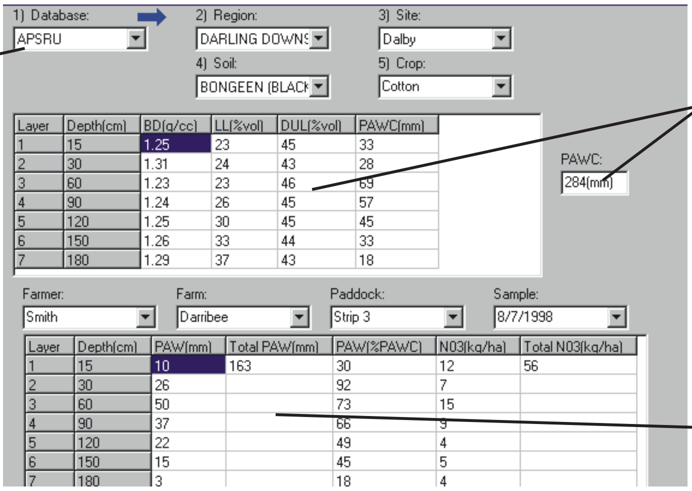


Farmer: Smith
Profile: APSRU
Farm: Darribee
Paddock: Strip 3
Sample date: 8/7/1998
Number of reps: 1

Layer	Depth(cm)	Wet(g)	Dry(g)	N03(mg/kg)
1	15	534	432	6
2	30	487	370	4
3	30	422	319	4
4	30	469	358	2
5	30	452	348	1
6	30	575	442	1
7	30	575	444	1

Wet and dry weight and nitrogen concentration of samples are inserted by farmer or consultant (Module 2)

Soil type, site and crop details from database (Module 5), or locally generated



1) Database: APSRU
2) Region: DARLING DOWNS
3) Site: Dalby
4) Soil: BONGEEN (BLACK
5) Crop: Cotton

Layer	Depth(cm)	BD(g/cc)	LL(%vol)	DUL(%vol)	PAWC(mm)
1	15	1.25	23	45	33
2	30	1.31	24	43	28
3	60	1.23	23	46	69
4	90	1.24	26	45	57
5	120	1.25	30	45	45
6	150	1.26	33	44	33
7	180	1.29	37	43	18

PAWC: 284(mm)

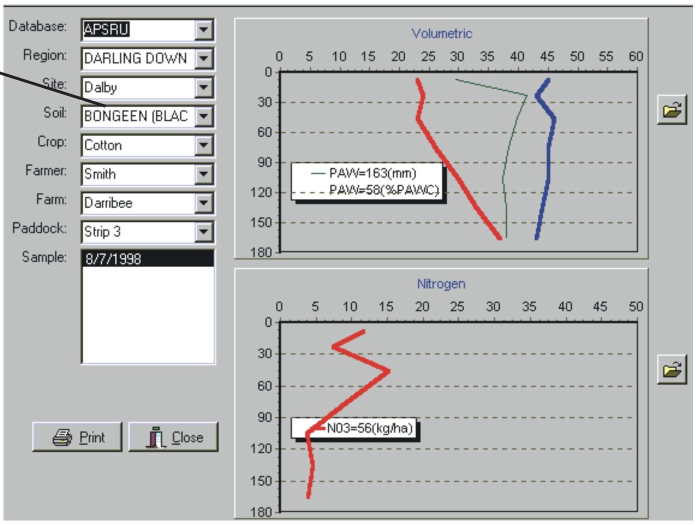
Farmer: Smith
Farm: Darribee
Paddock: Strip 3
Sample: 8/7/1998

Layer	Depth(cm)	PAW(mm)	Total PAW(mm)	PAW(%PAWC)	N03(kg/ha)	Total N03(kg/ha)
1	15	10	163	30	12	56
2	30	26		92	7	
3	60	50		73	15	
4	90	37		66	9	
5	120	22		49	4	
6	150	15		45	5	
7	180	3		18	4	

Bulk Density and PAWC of soil x crop combination for each layer and the whole profile (Module 4)

Water and available N calculation, based on soil physical characteristics, for each layer and the whole profile (Module 3)

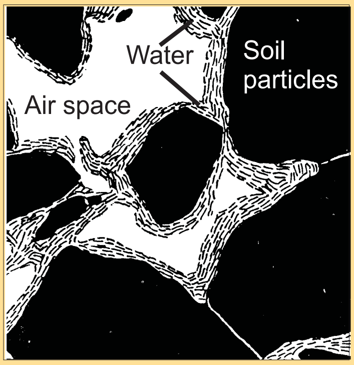
Details of farmer, paddock and sampling



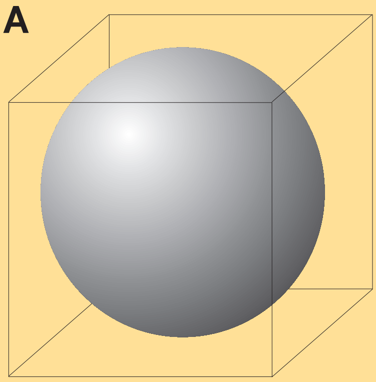
Database: APSRU
Region: DARLING DOWN
Site: Dalby
Soil: BONGEEN (BLAC
Crop: Cotton
Farmer: Smith
Farm: Darribee
Paddock: Strip 3
Sample: 8/7/1998

Results of available water and nitrogen presented graphically.
Data from a series of sampling dates can be compared on a single graph.

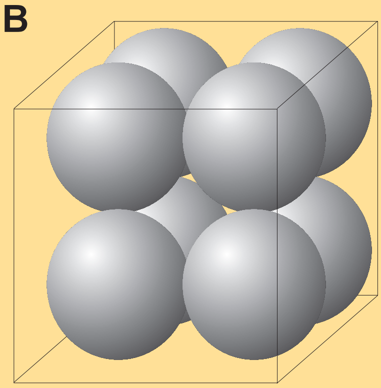
Water, air and soil particles



Water clings to the surface of soil particles, but drains out of large pore spaces. Plant roots can draw off only the ‘available’ part of the clinging water layer. Small particles that occupy the same soil volume as large particles have a greater surface area to which water can cling and smaller pore spaces. Water retention is related to the combined surface area of all the particles in a soil sample and the amount of fine pore space between them.



Sphere A represents a soil particle that occupies the same volume as the 8 particles of half its diameter in B.

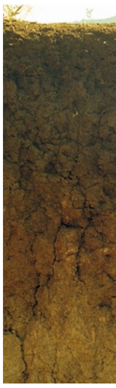


The volume and weight of the 8 spheres in B are the same as the large one in A, but their combined surfaces have twice the area. More of the ‘pore space’ between the small spheres will be occupied by water than between large spheres as less water will drain.

Clay particles have a diameter that is less than one tenth that of fine sand. The particles in a given mass of clay have a surface area at least 100 times greater than the same mass of fine sand. Thus clay has a higher capacity to hold water than does sand, but it releases to the root system a smaller proportion of the water it holds. Shrink-swell clays ‘make room’ for water to move in, and out from, between particles. As water is lost, this clay shrinks back to its ‘dry’ state.

(Top illlustration after Jenny, 1980)

Figure 1.1. Water, air and soil particle size



Plant available water capacity (PAWC)

The amount of water extracted by a plant depends on the soil's physical and chemical properties, and on root density, rooting depth, crop demand and the duration of crop growth. The blue and red areas represent the plant available water capacity (PAWC) for two crops which differ in their ability to extract water. Water stored in the red surface area is prone to evaporation and may not be available to the plant.

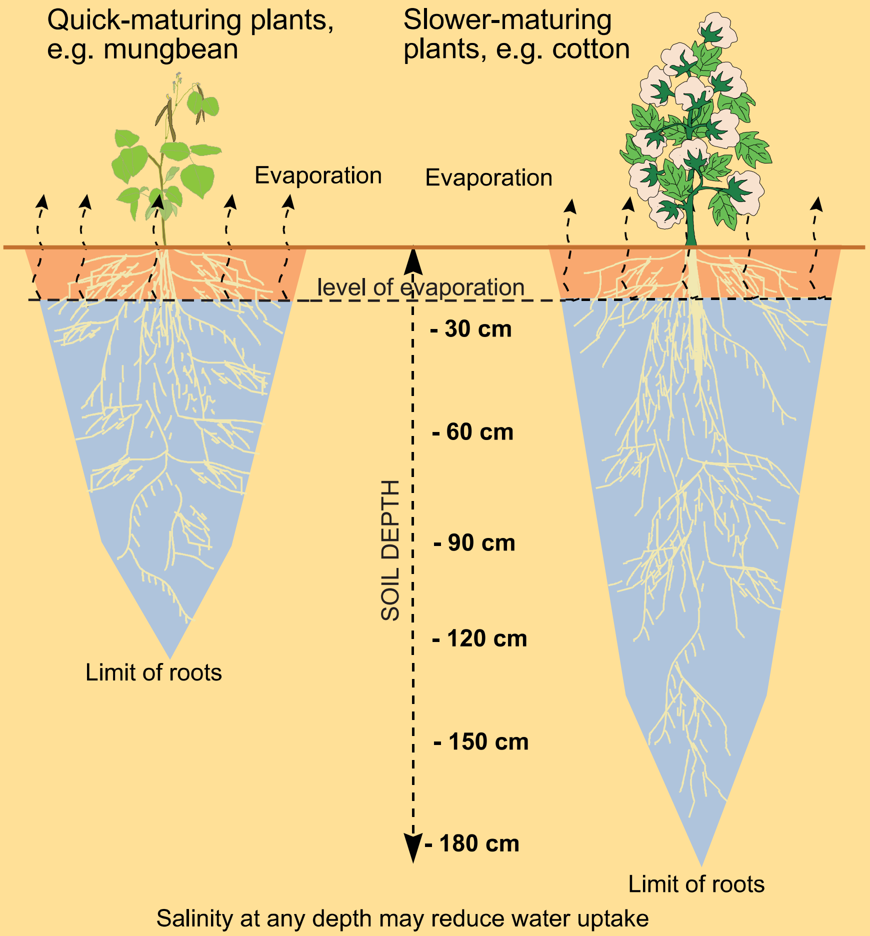


Figure 1.2. Plant available water capacity for two differing crops, represented as water 'buckets'.

Water storage

In cracking clay, the aggregates of particles (peds) swell as water moves into the space between the plate-shaped particles (less than .002 mm diameter). Upon drying, the aggregates shrink as water moves out from between the particles, and large cracks open in the soil between large clusters of peds. These shrink-swell soils are able to store more water than lighter-textured soils or rigid types formed from less reactive clays. This increased storage provides a more reliable water supply to crops between rainfall events, making cracking clay soils the preferred choice of farmers in the northern grain belt (see Module 4).

Sandy soils store the least water. They are not suited to cropping in the semi-arid subtropics because the amount that can be stored would rarely be sufficient to enable a crop to survive the frequent long periods between rainfall events.

Soil structure and cover affect water infiltration

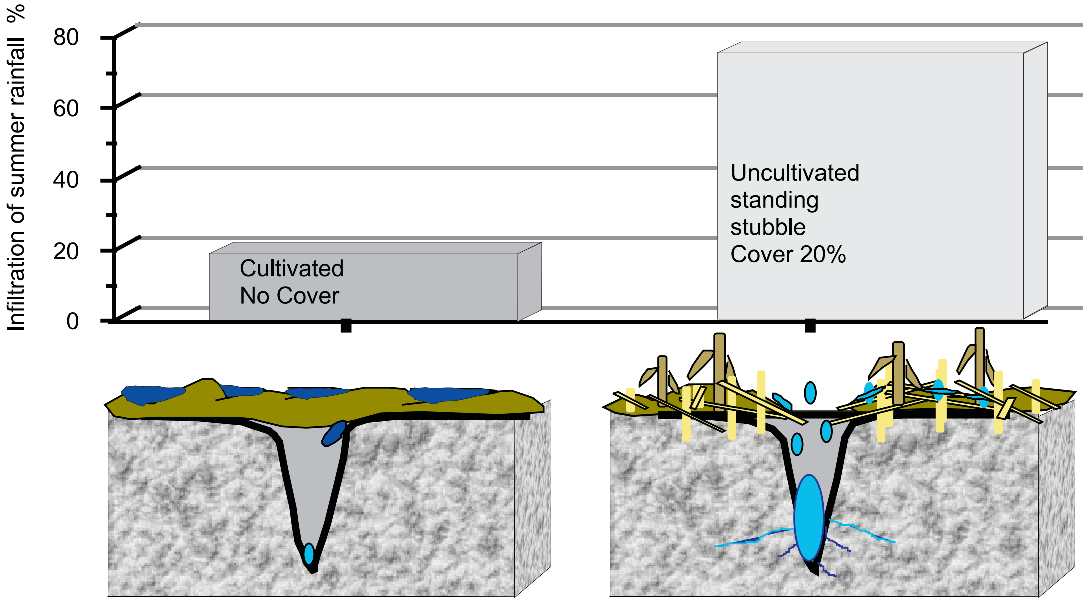
Apart from the capacity of the soil to store water, the rate of entry of water into the soil during rainfall is also crucial to successful farming.

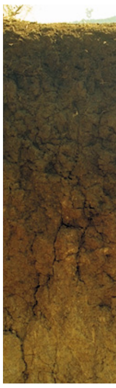
Infiltration of water into a dry cracking clay soil is initially rapid through the large open cracks, but water entry slows, as firstly the surface clay aggregates and then the large blocks of soil peds beneath the surface are wetted up and swell. Water from high intensity rainfall, or irrigation, will enter a dry cracked soil very rapidly through the open cracks; the water will then soak "sideways" into the large blocks of soil peds from the water-filled cracks.

The stability of aggregates and fine peds, and of the gaps between them, determines the rate of infiltration into a wet soil. Swelling will cause the peds to press together. However, if the peds are highly stable and internally cohesive, the gaps between them will remain sufficiently wide and sufficiently connected to allow significant downward flow of water. Infiltration when the surface soil is wet is also improved by the presence of residue (Figure1.3), the absence of compaction—which accompanies cultivation—and by a high concentration of soil organic matter. Cultivation imposes a risk of damage to fine peds causing blockage of the gaps between peds and aggregates upon which water flow depends.

Some soil shows hard-setting behaviour, in which particles become packed tightly together, showing little shrinkage upon drying. In these soils cultivation has a role in creating roughness at the surface, which generally improves infiltration of water, at least during the next rainfall event. Hard-setting may develop again, following a substantial fall of rain, on a soil that disperses rather than forming aggregates.

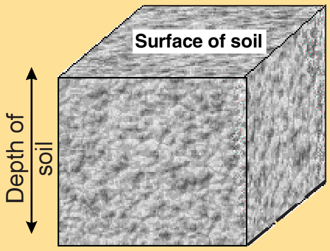
Figure 1.3. Rainfall infiltration over a summer fallow: an example of a cultivated paddock with no cover compared with an uncultivated paddock with 20% cover provided by standing stubble (Freebairn and Wockner 1996).



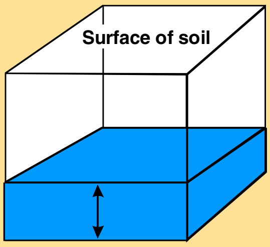


Connecting soil water and rainfall

Soil water can be considered in the same terms as rainfall, i.e. as millimetres of water, in the soil profile. The weight of water in a soil sample (called the gravimetric water content and expressed as a percentage of the dry soil weight) must be converted to millimetres of water. This can be explained by visualising a block of soil which contains an amount of water. If this water flowed into a single layer after removing the soil particles, this Volumetric Water Content can be seen as depth of water (in millimetres).



Water distributed throughout soil

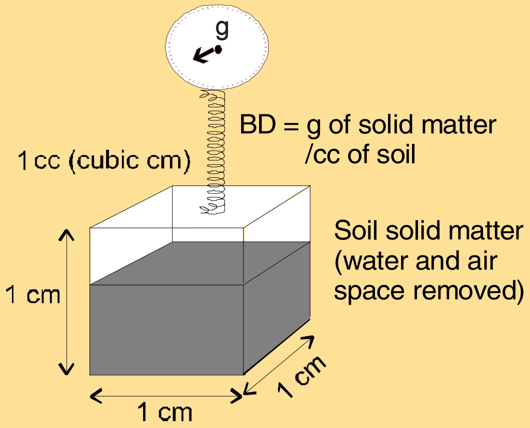


Equivalent depth of water after soil is 'removed'

To calculate this depth of water when we know the weight of water in a certain weight of soil—the gravimetric water %—we need to know the weight of soil solid matter in the block—its Bulk Density.

Bulk Density (BD)

Bulk density (g/cc) of soil solid matter is the weight of solid particles in 1 cubic centimetre of soil.



Once the bulk density is known, the weight of water per gram of soil can be converted to water volume per cc of soil volume, which is equivalent to the mm depth of water per cm soil depth. We can relate this directly to rainfall in mm.

For example:
Calculating mm of water in a soil layer that has a gravimetric water content of 40% and a BD of 1.3g/cc.
Volumetric water content = 40% x 1.3 g/cc
= 52% or 52 mm of water per 100 mm depth of soil

This calculation uses data from soil sampling procedures outlined in Module 2, and is integrated in Module 3 to estimate available water for the whole profile (Table 3.3). The measurement of PAWC, including BD, is explained in Module 4.

Organic matter, roots, and micro-organisms

Both long fallow and cultivation of the soil reduce soil organic matter, by reducing the rate of addition of residue; they also increase the surface area of particles of residue and organic matter exposed to soil organisms that consume organic residue.

This reduction of soil organic matter can be slowed, and possibly reversed, by management that increases the proportion of total rainfall that crops use. The practice of minimum or zero tillage generally improves rainfall capture (Figure 1.3 and Module 3) which in turn helps to increase both the crop yield and the amount of residue. If soil water storage is adequate, planting an ‘opportunity crop’ will use in-crop rainfall which might well run off from a fallow.

An opportunity crop makes use of the soil water while its canopy shades the soil surface, reducing evaporation.

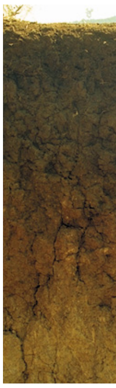
Recovery of water from the soil depends upon adequate root development. Soil compacted by machinery, or affected by sodicity, (see following section on Chemical factors) resists the penetration of roots.

Cracking soil, however, provides ‘freeways’ for the rapid extension of roots deep into a profile. When the soil is wet and cracks are closed, roots still experience less resistance to their extension in these crack pathways. Even when the soil is depleted of plant available water, root extension at depth may continue. Although little water remains to be extracted, the moist atmosphere, deep in the soil, enables roots to continue to extend downwards. If there happens to be some deeper extractable water these exploring roots will gain access to it.

The physical properties of the soil surface, especially the stability of soil peds, are influenced by the amount of organic matter, and by the level of microbial and faunal (small soil animals) activity. Soil that is high in phosphorus sustains high microbial and faunal activity, which is indicated by good crumb structure, tunnels that have been burrowed out by worms and insects, and an absence of surface crust. Soil that has a high calcium status generally has a robust and stable ped structure.

Summarising soil physical properties

- Soil texture is determined by the relative mix of fine and coarse particles.
- Soil structure reflects change in texture, mix of different clay minerals, and capacity for particle aggregation into peds and clusters of peds.
- Potential soil water storage depends on texture, and on the type of clay minerals present.
- Plant available water is highest in cracking clay soil.
- High phosphorus sustains microbes and microfauna which improve soil structure.
- High calcium imparts stability to peds, improving structure; sodicity causes dispersal of aggregates and hard-setting.
- Roots can extend rapidly down the ‘freeways’ provided by deep soil cracks.



Soil chemical properties

A soil laboratory analysis sheet provides information on the chemical characteristics of the soil.

This sort of analysis information has been available from commercial laboratories for many years (Figure 1.4).

RESULTS OF ANALYSIS*

* Values given indicate an adequate or favourable level.

Date of Sampling...............
Soil colour (Munsell).........
Soil Texture.......................
pH (1:5 water)...................

Organic Carbon % C.....
Nitrate nitrogen mg/kg.........
Sulphur mg/kg......................
Phosphorus (BSES) mg/kg...
Phosphorus (Colwell) mg/kg

Potassium meq/100g...........
Calcium meq/100g...............
Magnesium meq/100g.........
Sodium meq/100g................

Chloride mg/kg...................
Elec. Conduct. dS/m...........
Copper mg/kg......................
Zinc mg/kg..........................

CALCULATIONS
Calcium/Magnesium ratio....
Cation Exchange capacity meq/100g
Sodium % of cations...............
Elec. Conduct. (s.e.) ds/m.......

Organic Carbon - a measure of organic matter reserves which are an indicator of cropping history, and of the potential for nutrient release. Values between 1 and 2 are common in clay soil.

Nitrogen - available to the crop; moves through the soil profile with the water; may accumulate at depth. (Modules 2 and 3)

Sulphur - available to the crop; may move through the soil and accumulate at depth.

Phosphorus - The BSES test which is used in acid soils, may overestimate available P in alkaline clay soils.

The Colwell test is used in alkaline clay soils.

Chloride - indicator of the level of salinity.

Elec Conductivity - gauges salinity by indirect measurement. A measure of all salts in the soil solution.

Calcium/Magnesium Ratio - variation is associated with different levels of soil dispersion. Values below 0.1 indicate high dispersion and poor infiltration.

Cation Exchange Capacity - indicates potential capacity of soil to store nutrients, e.g calcium, potassium.

Sodium % - indicates a possible sodic effect.

Elec Conductivity (SE) - alternative value for conductivity adjusted for soil texture.

Texture - a rough guide to water storage capacity (higher in cracking clays and clay loams). (Module 5)

pH - above 7.0 alkaline; possible sodicity above 8.4; acid below 7.0; possible plant toxicity below 5.0

The three major cations - essential for plant growth. Exert great influence on soil structure, colour, and aggregate stability.

Sodium - a high level disperses aggregates, reducing pore space and infiltration rate.

Importance of trace elements depends on land use; these cations less available where pH is above 7.5.

Zinc - low levels often limit growth on clay soil. VAM increases uptake of zinc.

Figure 1.4. Explanatory notes for a sample laboratory analysis sheet.

Plant nutrients

All the nutrients needed for plant growth are found in the soil. The other major inputs to growth are water taken up from the soil and carbon dioxide from the atmosphere.

A major contributor to plant nutrient reserves in the soil is the residue from the breakdown of plants, small and large animals and soil flora (Figure 1.5).

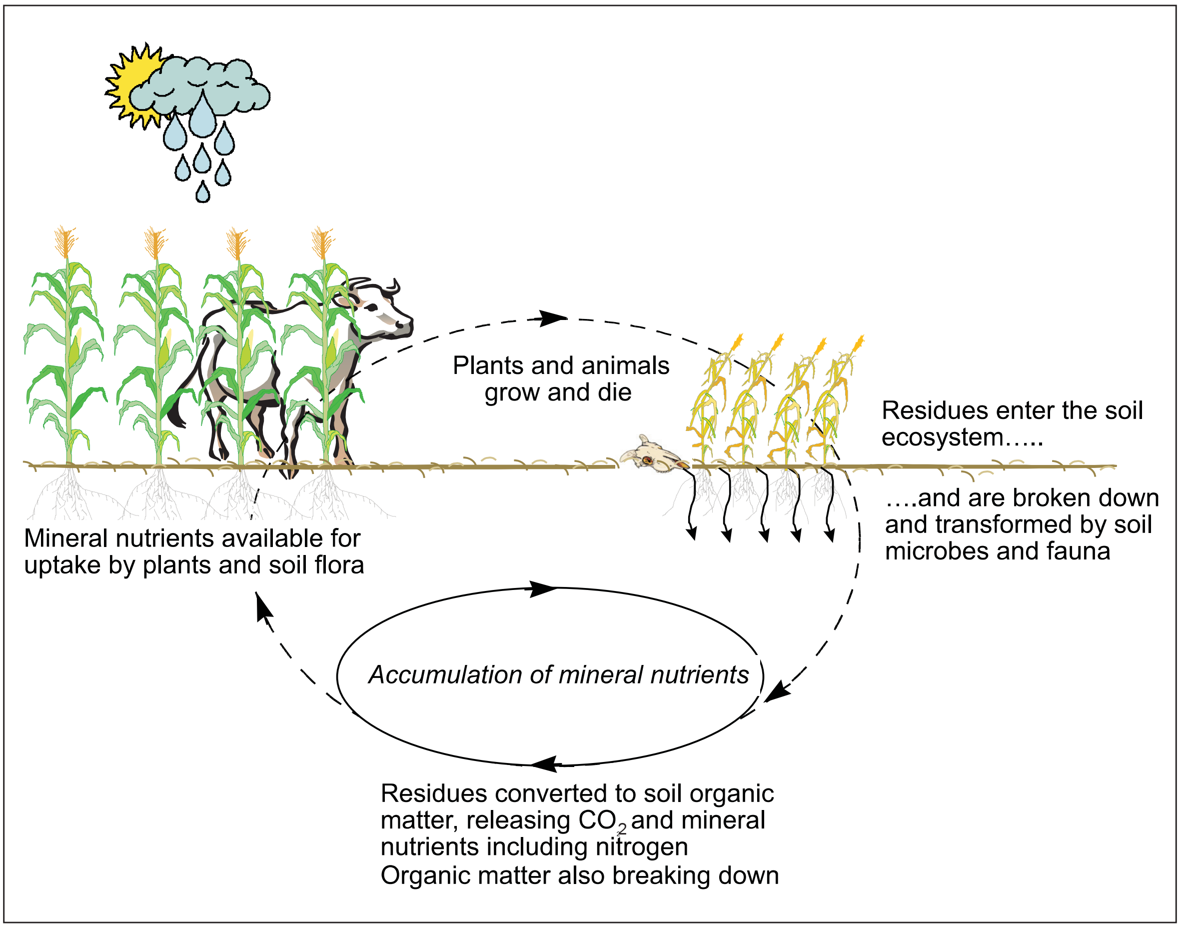
Plants take up nutrients almost exclusively in mineral form in solution, after the organic molecules, comprising mostly carbon, hydrogen, oxygen and nitrogen, have been broken down.

Nitrogen, phosphorus and sulphur are available to plants in soluble ‘mineral’ form, as nitrate (NO_3^-), phosphate (PO_4^{---}) and sulphate (SO_4^{--}). Nitrate and sulphate move freely in the soil solution and are carried down the profile by infiltrating water.

The general behaviour of phosphorus moving between different levels of availability is illustrated in Figure 1.6. Phosphate can be fixed by attachment to certain soil compounds, particularly aluminium and iron oxide, becoming unavailable for uptake by roots or soil organisms. This is a particular problem in red acid soils rich in iron and aluminium oxides. In highly acid soils, the sulphate anion can also become fixed and unavailable.

Most other nutrients are attached by electric charge to clay or organic particles as positively charged cations (single atoms such as potassium, magnesium and zinc), unattached to other elements though com-

Figure 1.5. The cycle of soil organic matter and nutrients



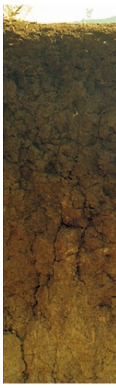
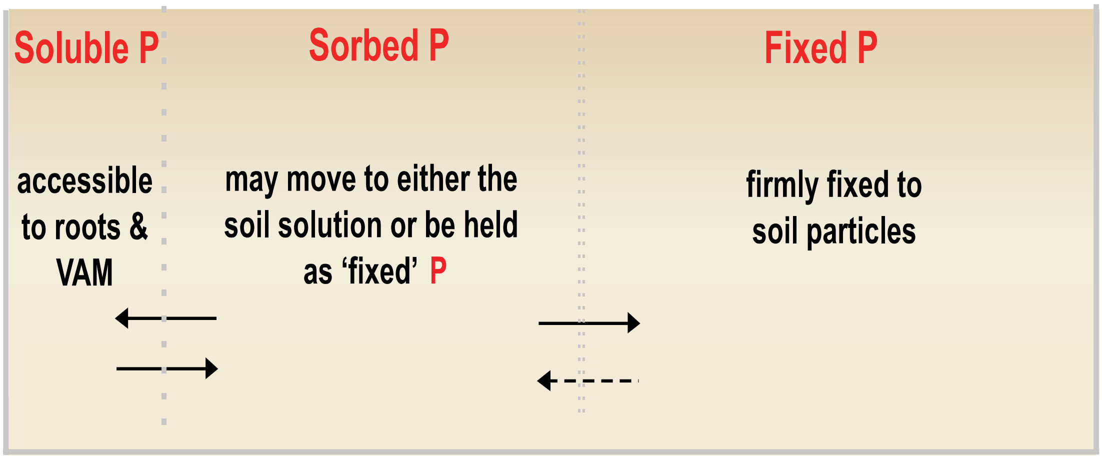


Figure 1.6. Soil phosphorus—the relationship between soluble (available) P and other forms



- This tank model is used to illustrate the two-way flow between P in solution, sorbed P held loosely, and fixed P held tightly, on soil particles. Soil tests measure P in solution and some sorbed P.
- The relative size of the three compartments differs with soil type and cropping history.
- Fertiliser P will mostly expand the soluble compartment, but in some soils some can move through the buffer reserve and become fixed. As fixed P is released only slowly, the soluble compartment will shrink as P is taken up by plants. Even though P is taken from the soil in products, change in concentration shown in tests might not reflect that loss, due to release of sorbed P.
- VAM fungi in the soil gain access to some of the P in solution which roots cannot access directly. A VAM filament can enter gaps between soil aggregates that are half as narrow as those that the root hair can enter.

plemented by anions located in the vicinity. Through an electrical exchange process, the plant root captures both cations and anions from the surface of soil particles or from the soil solution. The concentration of these nutrients in the soil can be determined by laboratory analysis. This analytical information is used by farmers to assist in making fertiliser decisions (see Figure 1.4).

pH affects nutrient availability

pH is an expression of acidity-alkalinity on a scale of 1–10. The chemical environment of the soil can be acid, neutral or alkaline. The ideal state is neutral which is the status of pure water, but generally there are influences which generate acidity (e.g. the movement through the soil of strong acid ions such as sulphate or nitrate) or alkalinity due to the accumulation of strongly basic ions (such as calcium and sodium)

The term pH was derived from the method of measurement of the concentration of hydrogen ions in a solution. This concentration is indicated by the electrical **p**otential in the solution between two **H**ydrogen electrodes. The lower the pH number, the higher the concentration of hydrogen ions; a drop of 1 unit of pH represents a ten-fold increase in the concentration of hydrogen (acid) ions.

The pH scale provides a useful indicator of some aspects of chemical properties and behaviour of the soil that affect plant growth. Alkaline clays generally contain a majority of ions of the bases calcium, magnesium, potassium and sodium.

Both extremely high and extremely low pH soils are unfavourable to plant growth. A high degree of acidity (below pH 5.5) may trigger the release in a toxic form of aluminium or manganese, while strong alkalinity (above pH 8.0) impairs uptake by the root of scarce trace element cations, such as copper, iron, manganese and zinc.

Converting laboratory analyses from mg/kg to kg/ha

Results of analyses for some nutrients are reported as weight of nutrient per unit weight of soil, i.e. mg/kg (equivalent to the old 'parts per million' or ppm).

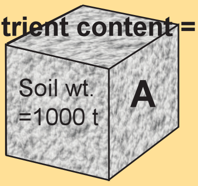
Understanding the conversion from mg/kg to kg/ha

A 10 cm layer of soil over 1 ha has a volume of 1000 cubic metres; the weight of soil will depend on its Bulk Density (BD) (see page 9).

The weights of 1000 cubic metres of two soils of different BD (A and B) are illustrated below. If the nutrient content is 10 mg/kg:

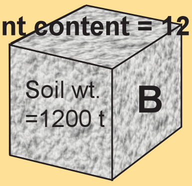
Soil A with BD of 1.0 g/cc will have a nutrient content of 10 kg/ha (10 x 1.0)
Soil B with BD of 1.2 g/cc will have a nutrient content of 12 kg/ha (10 x 1.2).

Nutrient content = 10 kg/ha



There is more nutrient in Soil B on an area basis because of its greater weight of soil on an area basis.

Nutrient content = 12 kg/ha



Salinity

High concentration of salts (mostly sodium chloride but also other soluble mineral salts) can cause a problem to crop production. A highly saline soil solution impairs the uptake of water because the dissolved salts lower the potential of water molecules to pass through the cell membrane into the root. The plant experiences a chemical drought. Excessive salinity commonly affects the lower profile in clay soils and may prevent roots from entering that layer.

Laboratory and field measurements of salinity are expressed as Electrical Conductivity. The critical values of EC vary between crops, but Table 1.1 is a guide. Local advice should be sought for crop-specific values.

Table 1.1. Plant response to salinity[a]

Conductivity (dS/m)[b]	Depression in yield
below 0.2	very low
0.2 to 0.5	low
0.5 to 0.7	medium
above 0.7	high

[a] measured on 1 part soil to 5 parts water

[b] deciSiemen per metre (= milliSiemen per cm)

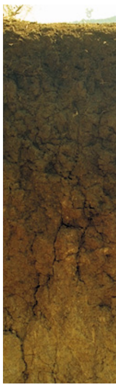
Sodicity

Sodicity can affect the physical properties of a soil.

When clay particles have a high proportion of their electric charges linked to sodium ions, they lose their normal tendency to cling together, and are inclined to disperse. Sodicity is shown by excessive swelling of the clay and dispersal of the fine particles that make up soil aggregates.

The mobilised fine particles block the larger pore spaces in the soil structure forming a 'hard-setting' or 'massive' layer of high bulk density. This reduction of pore space impedes the entry and storage of water in the soil mass, and interferes with root growth as few pores remain that are suitable for the entry of root hairs (greater than 14 microns diameter*). A high proportion of magnesium relative to calcium amplifies sodicity. Application of gypsum (calcium sulphate) will displace some of the sodium ions but this may be very expensive if deep layers of soil are affected.

[*1 micron is 1 thousandth of 1millimetre]



Summarising plant nutrients and chemicals

- Plant nutrients are recycled through the decomposition of organic matter.
- The mineral composition of the parent rock influences the level of soil nutrients such as phosphorus and the cations (calcium, potassium, magnesium, etc).
- Extremely high or low soil pH may impede uptake of some trace elements; low pH may cause toxicity to roots.
- Salinity affects water uptake resulting in a chemical drought at high EC.
- Excess sodium (sodicity) disperses fine particles into pore spaces reducing water infiltration and blocking root access.

Soil biological properties

Organic matter

The powerhouse of biological activity is the soil organic matter, ranging from fresh plant and animal residue and excreta to highly processed humus.

Analysis for organic carbon (% C) generally indicates the level of organic matter, although the presence of inert charcoal may distort the figure. A factor of 1.7 is used to convert % C to % organic matter.

Under undisturbed vegetation, organic carbon ranges from 2-3% C under brigalow forest to about 1% C under grasslands such as Queensland bluegrass or Mitchell grass. After continuous cultivation for 30–50 years, organic carbon levels drop well below 1% C, accompanied by a loss of soil structure. The level of organic matter in a soil is an equilibrium between incorporation of new material and the rate of oxidation, which is dependent on soil temperature and moisture. The return of plant material to the soil under cropping is reduced because of removal of harvested yield or from loss through burning or baling residues; cultivation also exposes a larger surface area of soil particles to the atmosphere, increasing the rate of oxidation.

The ratio of carbon to nitrogen is important. Incorporating a large amount of inert plant material (e.g. straw) may increase the physical organic matter but will not improve the level of vital or labile humus. Bacteria trying to digest (decompose) the straw will need to obtain their nitrogen from the small pool of available soil nitrogen, and this may make it unavailable to a succeeding crop.

Restoring organic matter and soil structure

The cracking clays do not suffer as great a loss of structure as other soil types because their shrinking and swelling nature maintains their ped structure.

Restoration of orgainc matter and structure in other soils can be advanced substantially only by reverting to grassland for a number of years. The fine fibrous roots of a pasture grass place its organic matter in intimate contact with soil particles in a totally different way to that of incorporating plant residues by mechanical means. Pasture leys of pure legumes (medic or lucerne in the southern regions or lablab, cowpea or butterfly pea in the subtropics) will raise soil nitrogen levels quickly but the plant residues break down too quickly to provide a lasting organic carbon increase.

However, a pasture solely of grass has limited potential because its total dry matter production, and depth of rooting, are restricted by low available nitrogen. Thus, restoration of fertility (organic matter and nitrogen) requires a mixed pasture of grass and legume.

Farming and soil biology

Soil biology is much affected by farming activity.

The plant residues that accumulate under mono-cropping are the specific food source for parasitic insects and diseases such as crown rot and root lesion nematode in wheat. Crop diversity encourages populations of competing organisms and reduces the build-up of specific pests and diseases.

Clean cultivation between crops incorporates residues causing rapid loss of soil organic matter, whereas biological activity is slower under zero tillage. Although nutrients are recycled more rapidly under cultivation, the favourable effects of surface residue and preserved organic matter on physical properties are reduced.

Maintaining a high soil nutrient status (especially of phosphorus) favours not only improved crop growth but also rejuvenates the population of beneficial soil micro-organisms and invertebrates.

Where or when soil water is adequate, opportunity cropping can improve rainfall use efficiency (i.e. the amount of plant material that grows for every mm of rain that falls. See Module 3). The residue from an opportunity crop improves the quantity of residue entering the organic cycle and so allows better capture of water in the next fallow. High productivity arising from good water and nitrogen management therefore improves organic matter.

VAM

If biological activity in the soil is greatly reduced by a long (10 to 18 month) fallow, necessitated by drought, the next crop may show symptoms of phosphorus and zinc deficiency. This is because of reduced activity of VAM (vesicular arbuscular mycorrhiza) fungi. These VAM fungi become attached to the plant roots, thereby greatly increasing the surface area of the root system. A crop with a strong VAM association has a greatly enhanced capacity to forage for zinc, phosphorus and also potassium.

VAM fungi take 2 to 3 months to become fully active after a long break between host crops, especially if the fallow has been free of weeds.

Summarising biological properties and organic matter

- Organic matter provides energy and nutrients to soil organisms, and replenishes the reserve of plant-available nutrients in the soil.
- Diversity of soil organisms depends on a supply of residue from diverse plants.
- Active and diverse soil organisms improve the physical and nutrient-supplying properties of the soil, and reduce the activity of soil-borne pathogens.
- VAM fungi assist roots to take up scarce phosphorus and zinc, and require careful management to remain active.
- Cropping, and especially baling or burning, limit the flow of crop residues into the soil due to export or loss of product from the paddock.
- Changed farming methods can reverse soil degradation by halting the run-down of organic matter.
- Organic matter is best replenished by the fine root system of a medium-term ley grass–legume pasture.